



**University of  
Zurich**<sup>UZH</sup>

**Zurich Open Repository and  
Archive**

University of Zurich  
University Library  
Strickhofstrasse 39  
CH-8057 Zurich  
[www.zora.uzh.ch](http://www.zora.uzh.ch)

---

Year: 2014

---

## Search for stop and higgsino production using diphoton Higgs boson decays

CMS Collaboration ; Chatrchyan, S ; Khachatryan, V ; Sirunyan, A M ; et al ; Chiochia, V ;  
Kilminster, B ; Robmann, P

**Abstract:** Results are presented of a search for a "natural" supersymmetry scenario with gauge mediated symmetry breaking. It is assumed that only the supersymmetric partners of the top-quark (stop) and the Higgs boson (higgsino) are accessible. Events are examined in which there are two photons forming a Higgs boson candidate, and at least two b-quark jets. In 19.7 inverse femtobarns of proton-proton collision data at  $\sqrt{s} = 8$  TeV, recorded in the CMS experiment, no evidence of a signal is found and lower limits at the 95% confidence level are set, excluding the stop mass below 360 to 410 GeV, depending on the higgsino mass.

DOI: <https://doi.org/10.1103/PhysRevLett.112.161802>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-92182>

Journal Article

Accepted Version

Originally published at:

CMS Collaboration; Chatrchyan, S; Khachatryan, V; Sirunyan, A M; et al; Chiochia, V; Kilminster, B; Robmann, P (2014). Search for stop and higgsino production using diphoton Higgs boson decays. Physical Review Letters, 112:161802.

DOI: <https://doi.org/10.1103/PhysRevLett.112.161802>

CERN-PH-EP/2013-226  
2013/12/12

CMS-SUS-13-014

# Search for stop and higgsino production using diphoton Higgs boson decays

The CMS Collaboration\*

## Abstract

Results are presented of a search for a “natural” supersymmetry scenario with gauge mediated symmetry breaking. It is assumed that only the supersymmetric partners of the top-quark (stop) and the Higgs boson (higgsino) are accessible. Events are examined in which there are two photons forming a Higgs boson candidate, and at least two b-quark jets. In  $19.7 \text{ fb}^{-1}$  of proton-proton collision data at  $\sqrt{s} = 8 \text{ TeV}$ , recorded in the CMS experiment, no evidence of a signal is found and lower limits at the 95% confidence level are set, excluding the stop mass below 360 to 410 GeV, depending on the higgsino mass.

*Submitted to Physical Review Letters*



The recent measurements of the properties of the new boson with mass around 126 GeV by ATLAS [1, 2] and CMS [3, 4] experiments confirm that it is consistent with the standard model (SM) Higgs boson. One of the most important problems in particle physics is now to understand why the boson’s mass is so small compared to the Planck scale. Supersymmetry (SUSY) offers an elegant solution to this hierarchy problem. Although experimental searches have found no signs of it so far and the simplest SUSY models have become increasingly more constrained, there remain very large yet unprobed areas of SUSY parameter space that can still be “natural”, i.e. have a fairly small amount of fine tuning.

The essential requirement of “natural” SUSY is that the masses of the superpartners of the top quark and the Higgs bosons, the stop and the higgsinos, be light (see, e.g. [5, 6]). This Letter describes a search we performed for events with a topology motivated by SUSY with a gauge mediated SUSY breaking (GMSB) model [7–10]. Complete GMSB models are considered with a minimal number of accessible SUSY partners to satisfy the naturalness requirements, namely the right-handed stop and higgsinos.

The lightest chargino ( $\tilde{\chi}_1^\pm$ ) and neutralinos ( $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ ) in this case are almost pure higgsinos and are therefore almost mass-degenerate.

Pairs of higgsinos are produced either directly through electroweak production or through right-handed stop-antistop pairs (strong production) with cascade decays

$$\tilde{t}_R \rightarrow b\tilde{\chi}_1^+ \text{ or } \tilde{t}_R \rightarrow t\tilde{\chi}_i^0, \quad (1)$$

where  $i = 1, 2$ . The  $\tilde{\chi}_1^\pm$  ( $\tilde{\chi}_2^0$ ) subsequently decays into a very off-shell  $W^\pm$  ( $Z$ ) boson and a  $\tilde{\chi}_1^0$ . (Here, and in what follows, the charge-conjugate final states are also implied.) The near mass degeneracy of the higgsino states requires the off-shell boson decay products to be very soft.

The decay of the lightest neutralino in all cascades is

$$\tilde{\chi}_1^0 \rightarrow H\tilde{G} \text{ or } \tilde{\chi}_1^0 \rightarrow Z\tilde{G}, \quad (2)$$

where  $\tilde{G}$  is the gravitino. The branching fractions of  $\tilde{\chi}_1^0$  decays depend on SUSY parameters. For a significant portion of the parameter space, neutralino decays into Higgs bosons dominate. This includes regions of low  $\tan\beta$ , the ratio of the vacuum expectation values of the two SUSY Higgs doublets, and negative values of the higgsino mass term  $\mu$  [11].

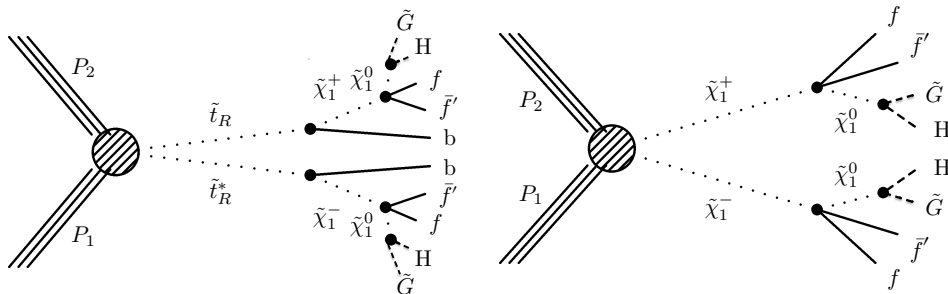


Figure 1: Example Feynman diagram of strong (left) and electroweak (right) higgsino production. The jets or leptons resulting from transitions between higgsinos are extremely soft in both diagrams due to the near mass degeneracy among the higgsinos.

The final state of interest, therefore, has two Higgs bosons, some missing energy from the gravitinos escaping detection, and, in the case of strong production, two bottom (or top, if

kinematically allowed) quarks from stop decays, as shown in Fig. 1. SM backgrounds, e.g. from top quark pair production, are suppressed by taking advantage of the known Higgs boson mass and by considering the case when at least one of the Higgs bosons decays into two photons and at least two b-quarks are present from either Higgs or stop decays. This approach also allows us to use diphoton mass sidebands for an estimate of the background from data, without sensitivity to the exact composition of the background, which is dominated by QCD production of  $\gamma\gamma b\bar{b}$  events and  $\gamma b\bar{b} + j$  events with the jet being misidentified as a photon.

We use a data sample of  $19.7 \text{ fb}^{-1}$  collected during the LHC 8 TeV running with the CMS detector, which is described in detail elsewhere [12]. The detector comprises a silicon pixel and strip tracker covering the pseudorapidity range  $|\eta| < 2.4$  (where  $\eta = -\ln[\tan(\theta/2)]$  and  $\theta$  is the polar angle of the particle with respect to the counterclockwise proton beam direction) and electromagnetic and hadronic calorimeters, which cover  $|\eta| < 3.0$  and  $|\eta| < 5.0$ , respectively. The tracking and calorimeter systems are housed inside a 3.8 T solenoidal magnet. Muon chambers are imbedded in the iron return yoke of the solenoid up to pseudorapidity of  $|\eta| < 2.4$ . Events are required to pass a suite of diphoton triggers that impose mild shower shape and isolation requirements and demand transverse energies ( $E_T = E \cdot \sin \theta$ ) above 36 and 22 GeV for the leading and the sub-leading photon, respectively.

The signal is simulated for a grid of higgsino and stop masses using the MADGRAPH 5 v.1.5.4 [13] and PYTHIA 6.4.22 [14] generators and fast simulation of the CMS detector [15]. The next-to-leading order (NLO) cross sections (shown in Fig. 2) are calculated using PROSPINO 2.1 [16–21]. The higgsino mass splittings  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^+}$  and  $m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$  are set to 5 GeV, and a 100% branching fraction is assumed for the  $\tilde{\chi}_1^0 \rightarrow H\tilde{G}$  decay. All other superpartners have masses too heavy to influence SUSY production at 8 TeV.

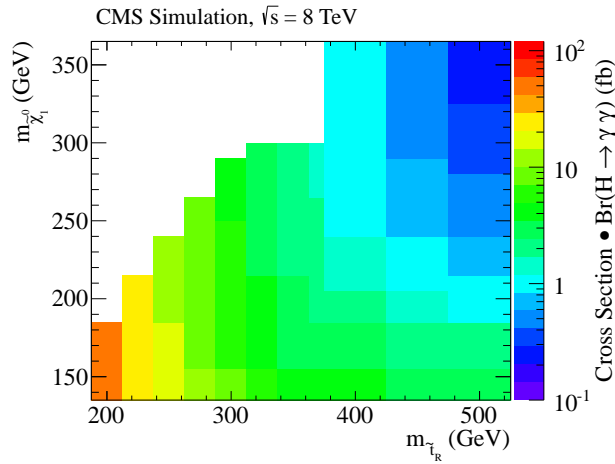


Figure 2: Cross section times branching ratio  $\text{Br}(H \rightarrow \gamma\gamma)$  as a function of stop and higgsino masses.

Photon candidates are reconstructed from the energy deposits in the electromagnetic calorimeter by grouping the calorimeter's data channels into superclusters [22, 23]. Photons are required to register in the barrel portion of the calorimeter ( $|\eta| < 1.4442$ ) and to pass shower shape and isolation requirements. To reject electrons misidentified as photons, photons are also required not to have associated hit patterns in the pixel detector consistent with a track. Photon energies are calculated using multivariate regression [4, 23].

The particle-flow (PF) algorithm [24] is used to reconstruct individual particles (PF candidates)

in the events, combining all available sub-detector information in a coherent and optimal manner. Jets are reconstructed from the PF particles using the anti- $k_T$  [25] algorithm with a distance parameter of 0.5 and are required not to overlap with the two leading photons by imposing a requirement  $\Delta R > 0.6$ , where  $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$  and  $\phi$  is the azimuthal angle. Transverse momentum and  $\eta$ -dependent corrections to the jet energies are applied to account for residual effects of non-uniform detector response. The pileup contribution is estimated and subtracted from the jet energy using the jet area method [26] on an event-by-event basis. The combined secondary vertex (CSV) algorithm [27] is employed to identify jets that originate from a bottom quark.

The missing transverse energy ( $E_T^{\text{miss}}$ ) of the event is computed as the magnitude of the vectorial sum of the transverse momenta of all PF candidates [24].

Events are selected if they have at least two identified photons with transverse energies above 40 and 25 GeV for the leading and sub-leading photons, respectively. Events are also required to have at least two jets with transverse energy above 30 GeV and  $|\eta| < 2.4$  and satisfying the loose (CSV-loose) b-tag requirements, at least one of which also must pass the medium (CSV-medium) requirement [27].

The events with diphoton mass between 120 and 131 GeV constitute the *signal sample*, while the events with mass between 103 and 118 GeV and between 133 and 163 GeV compose the *lower sideband* and *upper sideband* samples, respectively.

In the investigated SUSY signal, b-quark jets can originate from decays of the other Higgs boson and from decays of stop. This is exploited by separating events into three categories with different expected background as follows: (i) events with at least one additional CSV-loose b-quark jet in addition to the two (i.e. events with three or more b-quark jets), (ii) events for which the invariant mass of the two b-quark jets is within a Higgs mass window from 95 to 155 GeV, (iii) all other events.

The distribution of signal events among the three categories depends on the stop and higgsino masses. For small stop-higgsino mass differences, most of the signal populates category (ii), while for large mass differences categories (i) and (iii) dominate.

The search is performed independently in the three categories and the results are combined, leading to as much as 35% improvement in expected SUSY cross section limits compared to the analysis without categorization.

The peaking background from the SM Higgs boson production with subsequent diphoton decay is found negligible using MC simulation. The diphoton mass sidebands are used to derive an estimate of all other SM background processes from data.

The diphoton distribution is fitted using a power law from 103 to 163 GeV [28]. The region from 118 to 133 GeV, corresponding to the signal region plus the 2 GeV “buffers” on each side of the signal region, is excluded from the fitter’s consideration to prevent potential signal from affecting the background estimate. The result of the fit is used to calculate the normalization of the background. The effects of various other fit functions have been explored, and the resulting changes in the estimated background yields are well within the uncertainty in the fit function integral from the power law fit. The fit and background estimates are done independently in all three event categories.

Binned background distributions of relevant kinematic variables are obtained for each event category separately from the lower and upper sidebands and are weighted according to the fit function integrals. This provides two independent estimates of the distribution of the SM

background in the corresponding variable. No significant correlations are observed between the diphoton mass and other kinematic variables. However, to account for possible correlations, the background yield is conservatively assumed to be bounded by the independent background estimates from the upper and lower sidebands. The background prediction using this bound as a systematic uncertainty is calculated as follows. The main background estimate in each bin of a kinematic variable is formed by taking an average of the two background estimates from the sidebands. Half the difference between the two estimates is taken as a systematic uncertainty for that bin, so that the central value and its uncertainty spans the range between the two estimates coming from the lower and upper sidebands. For the main variable used in this analysis,  $E_T^{\text{miss}}$ , the background uncertainty is dominated by the statistical uncertainty in the sideband samples. The small correlation between the bin errors, originating from the common normalization from the fit, is taken into account during the statistical analysis described below.

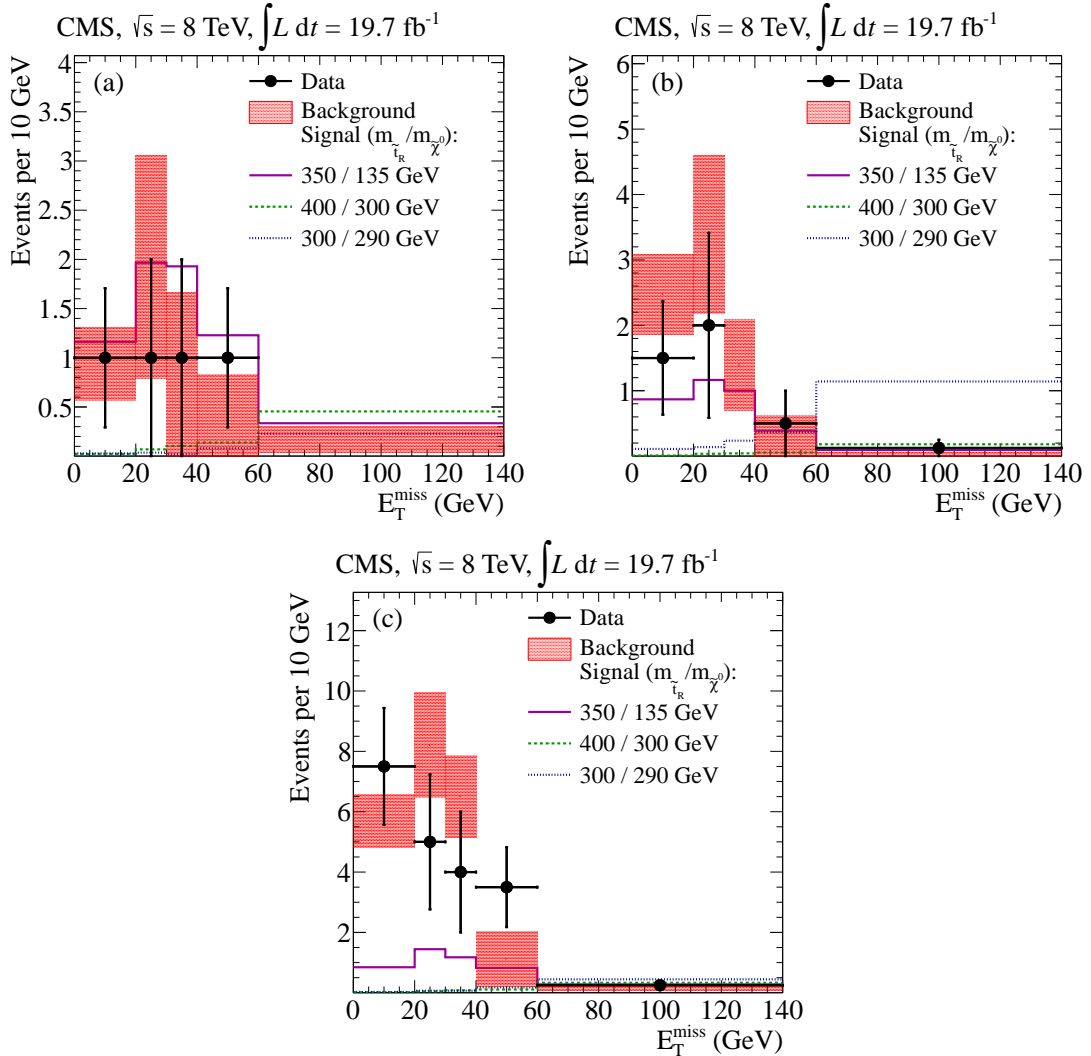


Figure 3:  $E_T^{\text{miss}}$  distributions for the data, background predictions, and representative signals for the three event categories (i), (ii), and (iii) in frames (a), (b) and (c), respectively. For each histogram, the last bin includes the overflow.

The observed distributions of  $E_T^{\text{miss}}$  are shown in Fig. 3 separately for the three event cate-

gories, together with the background estimates from the above procedure and the expected distributions from three characteristic signal points. Table 1 shows the expected signal yields, background predictions, and observed event counts for the three event categories. The observations are in agreement with the background predictions.

Table 1: Expected and observed event counts. The yields for three signal points are shown for comparison indicating  $m_{\tilde{t}_R}$  and  $m_{\tilde{\chi}_1^0}$  in GeV, respectively.

Category	(i)	(ii)	(iii)
signal 350 / 135	10.7	2.0	6.8
signal 300 / 290	2.1	10.1	3.9
signal 400 / 300	4.0	1.4	2.8
expected background	$6.7 \pm 1.4$	$10.5 \pm 1.8$	$29.7 \pm 2.8$
observed	6	7	33

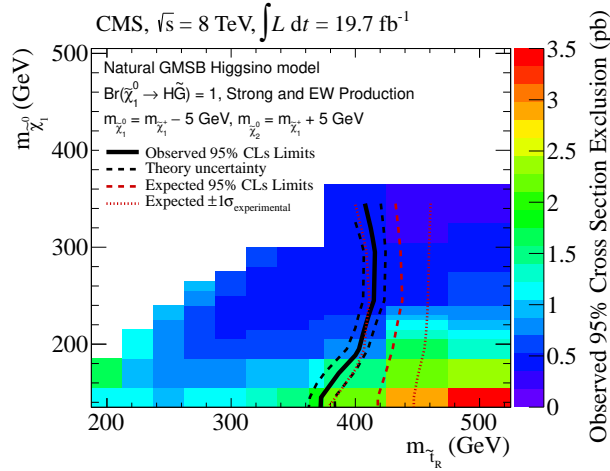


Figure 4: Limits on SUSY production cross sections for different stop and higgsino masses. The regions to the left of the contours are expected (thick dash/red) and observed (solid/black) to be excluded at the 95% confidence level. Black dashed curves reflect the theoretical uncertainty on the cross section. Red dotted curves correspond to one standard deviation in expected sensitivity.

Since the data agree with the expected background we proceed to set limits on the SUSY model described above. The expected limits were calculated using a variety of kinematic variables and it was determined that  $E_T^{\text{miss}}$  is the single most sensitive variable.

The observed  $E_T^{\text{miss}}$  distributions for the three event categories, shown in Fig. 3, together with the signal and background expectations listed in Table 1, are used as input to the limit setting procedure.

A frequentist LHC-style profiled likelihood test statistic is used [29–31]. For each model mass point, the modified frequentist CL<sub>s</sub> method is used to calculate upper limits on the cross section for the model.

The dominant uncertainty in the analysis is the statistical uncertainty of the background prediction. The leading sources of systematic uncertainties are the b-quark jet identification efficiency and the jet energy scale. The magnitude of the uncertainties depends on the event category and  $E_T^{\text{miss}}$ . For b-quark jet identification it varies from 1 to 5% for categories with two b-quark jets



and from 6 to 17% for the three or more b-quark jets. For the jet energy scale, the uncertainty is important only for  $E_T^{\text{miss}}$  values below 40 GeV and varies from 7 to 43%.

Other sources of systematic uncertainty in the expected signal yield include the uncertainties in integrated luminosity (2.6%) [32], the diphoton trigger efficiency (0.1%), the photon reconstruction and identification efficiency (1%), and the photon resolution uncertainty (1%) [4]. All systematic uncertainties are correlated among the event categories and are treated as nuisance parameters in the likelihood, profiled according to their estimated value.

Fig. 4 shows the limits on the GMSB model in the stop-higgsino mass plane. Depending on the higgsino mass, and conservatively using the minus-one-standard-deviation value for the theoretical cross section [16], stop masses below 360 to 410 GeV are excluded at the 95% confidence level, corresponding to the region to the left of the thin dashed black line in Fig. 4.

To summarize, a search for a “natural” SUSY scenario with light higgsinos and a stop was performed, using Higgs tagging in the diphoton decay mode, in a final state containing at least two photons and two or more b-quark jets. No evidence for a signal is observed, and 95% confidence level limits are set in the stop-higgsino mass plane, excluding a significant portion of the “natural” parameter space up to stop masses of 410 GeV.

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPCenter, IPST, STAR and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

## References

- [1] ATLAS Collaboration, “Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC”, *Phys. Lett. B* **726** (2013) 88, doi:10.1016/j.physletb.2013.08.010, arXiv:1307.1427.
- [2] ATLAS Collaboration, “Evidence for the spin-0 nature of the Higgs boson using ATLAS data”, *Phys. Lett. B* **726** (2013) 120, doi:10.1016/j.physletb.2013.08.026, arXiv:1307.1432.
- [3] CMS Collaboration, “Study of the Mass and Spin-Parity of the Higgs Boson Candidate via its Decays to Z Boson Pairs”, *Phys. Rev. Lett.* **110** (2013) 081803, doi:10.1103/PhysRevLett.110.081803, arXiv:1212.6639.

- [4] CMS Collaboration, “Observation of a new boson with mass near 125 GeV in pp collisions at  $\sqrt{s} = 7$  and 8 TeV”, *JHEP* **1306** (2013) 081, doi:10.1007/JHEP06(2013)081, arXiv:1303.4571.
- [5] R. Barbieri and G. F. Giudice, “Upper Bounds on Supersymmetric Particle Masses”, *Nucl. Phys. B* **306** (1988) 63, doi:10.1016/0550-3213(88)90171-X.
- [6] M. Papucci, J. T. Ruderman, and A. Weiler, “Natural SUSY endures”, *JHEP* **1209** (2012) 035, doi:10.1007/JHEP09(2012)035, arXiv:1110.6926.
- [7] S. Dimopoulos, M. Dine, S. Raby, and S. D. Thomas, “Experimental signatures of low-energy gauge mediated supersymmetry breaking”, *Phys. Rev. Lett.* **76** (1996) 3494, doi:10.1103/PhysRevLett.76.3494, arXiv:hep-ph/9601367.
- [8] S. Ambrosanio et al., “Search for supersymmetry with a light gravitino at the Fermilab Tevatron and CERN LEP colliders”, *Phys. Rev. D* **54** (1996) 5395, doi:10.1103/PhysRevD.54.5395, arXiv:hep-ph/9605398.
- [9] K. T. Matchev and S. D. Thomas, “Higgs and Z boson signatures of supersymmetry”, *Phys. Rev. D* **62** (2000) 077702, doi:10.1103/PhysRevD.62.077702, arXiv:hep-ph/9908482.
- [10] K. Howe and P. Saraswat, “Excess Higgs production in neutralino decays”, *JHEP* **1210** (2012) 065, doi:10.1007/JHEP10(2012)065, arXiv:1208.1542.
- [11] P. Meade, M. Reece, and D. Shih, “Prompt decays of general neutralino NLSPs at the Tevatron”, *JHEP* **1005** (2010) 105, doi:10.1007/JHEP05(2010)105, arXiv:0911.4130.
- [12] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [13] J. Alwall et al., “MadGraph 5: going beyond”, *JHEP* **1106** (2011) 128, doi:10.1007/JHEP06(2011)128, arXiv:1106.0522.
- [14] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 physics and manual”, *JHEP* **0605** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
- [15] CMS Collaboration, “The fast simulation of the CMS Detector at the LHC”, in *International Conference on Computing in High Energy and Nuclear Physics (CHEP 2010). J. Phys.: Conference Series* **331** (2011) 032049. doi:10.1088/1742-6596/331/3/032049.
- [16] M. Krämer et al., “Supersymmetry production cross sections in pp collisions at  $\sqrt{s} = 7$  TeV”, (2012). arXiv:1206.2892.
- [17] W. Beenakker, R. Hopker, M. Spira, and P. M. Zerwas, “Squark and gluino production at hadron colliders”, *Nucl. Phys. B* **492** (1997) 51, doi:10.1016/S0550-3213(97)80027-2, arXiv:hep-ph/9610490.
- [18] A. Kulesza and L. Motyka, “Threshold resummation for squark-antisquark and gluino-pair production at the LHC”, *Phys. Rev. Lett.* **102** (2009) 111802, doi:10.1103/PhysRevLett.102.111802, arXiv:0807.2405.
- [19] W. Beenakker et al., “Soft-gluon resummation for squark and gluino hadroproduction”, *JHEP* **0912** (2009) 041, doi:10.1088/1126-6708/2009/12/041, arXiv:0909.4418.

- [20] W. Beenakker et al., “Squark and Gluino Hadroproduction”, *Int. J. Mod. Phys. A* **26** (2011) 2637, doi:10.1142/S0217751X11053560, arXiv:1105.1110.
- [21] W. Beenakker, R. Hopker, and M. Spira, “PROSPINO: A Program for the production of supersymmetric particles in next-to-leading order QCD”, (1996).  
arXiv:hep-ph/9611232.
- [22] CMS Collaboration, “Photon reconstruction and identification at  $\sqrt{s} = 7$  TeV”, CMS Physics Analysis Summary CMS-PAS-EGM-10-005, (2010).
- [23] CMS Collaboration, “Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at  $\sqrt{s} = 7$  TeV”, *JINST* **8** (2013) 09009, doi:10.1088/1748-0221/8/09/P09009, arXiv:1306.2016.
- [24] CMS Collaboration, “Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV”, CMS Physics Analysis Summary CMS-PAS-PFT-10-002, (2010).
- [25] M. Cacciari, G. P. Salam, and G. Soyez, “The anti- $k_t$  jet clustering algorithm”, *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.
- [26] M. Cacciari and G. P. Salam, “Pileup subtraction using jet areas”, *Phys. Lett. B* **659** (2008), no. 12, 119, doi:10.1016/j.physletb.2007.09.077, arXiv:0707.1378.
- [27] CMS Collaboration, “Identification of b-quark jets with the CMS experiment”, *JINST* **8** (2013) P04013, doi:10.1088/1748-0221/8/04/P04013, arXiv:1211.4462.
- [28] CMS Collaboration, “Search for stop and higgsino production using diphoton Higgs boson decays”, (2013). The fits of diphoton mass distributions and distributions of considered kinematic variables are shown in the Appendix.
- [29] ATLAS Collaboration, CMS Collaboration, and LHC Higgs Combination Group, “Procedure for the LHC Higgs boson search combination in Summer 2011”, Technical Report CMS-NOTE-2011-005. ATL-PHYS-PUB-2011-11, CERN, Geneva, (Aug, 2011).
- [30] T. Junk, “Confidence level computation for combining searches with small statistics”, *Nucl. Instrum. Meth. A* **434** (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.
- [31] A. L. Read, “Presentation of search results: The  $CL_s$  technique”, *J. Phys. G* **28** (2002) 2693, doi:10.1088/0954-3899/28/10/313.
- [32] CMS Collaboration, “CMS Luminosity Based on Pixel Cluster Counting - Summer 2013 Update”, CMS PAS LUM-13-001, (2013).

## A Diphoton mass fits

Figures 5, 6, and 7 show the diphoton mass distributions in the three event categories and the fits to a power law.

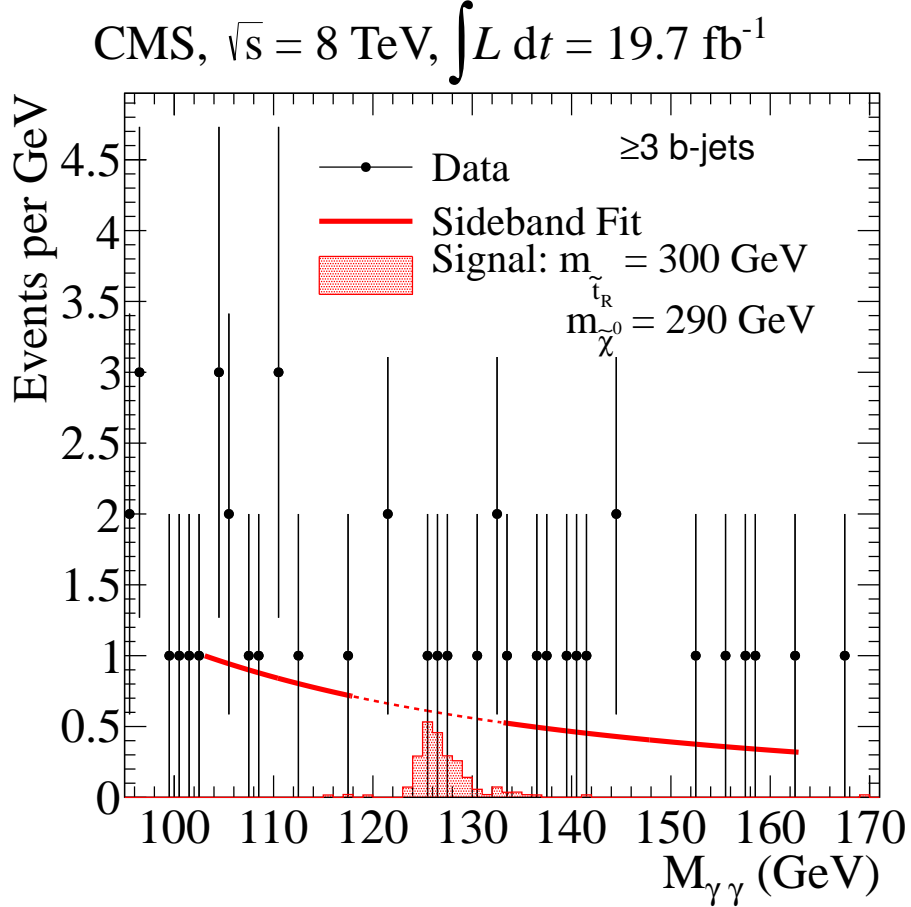


Figure 5: Diphoton mass distribution (points with errors) in event category (i) and the power law fit (thick red line). The interval from 118 to 133 GeV is excluded from the fit.

## B Other kinematic variables

In addition to  $E_T^{\text{miss}}$ , the following kinematic variables were studied:

- $S_T$ , defined as a scalar sum of  $p_T$  of all jets and photons in the event;
- $H_T$ , defined as a scalar sum of  $p_T$  of all jets in the event;
- $B_T$ , defined as a scalar sum of  $p_T$  of all b-quark jets in the event;
- $H_T^{\text{miss}}$ , defined as an absolute value of a vector sum of  $\vec{p}_T$  of all jets in the event;
- $p_T^{\gamma\gamma}$ , defined as a  $p_T$  of the Higgs boson candidate.

Figures 8, 9, 11, 10, and 12 show the expected and observed distributions of these variables for the three event categories combined, together with expected signal contribution.

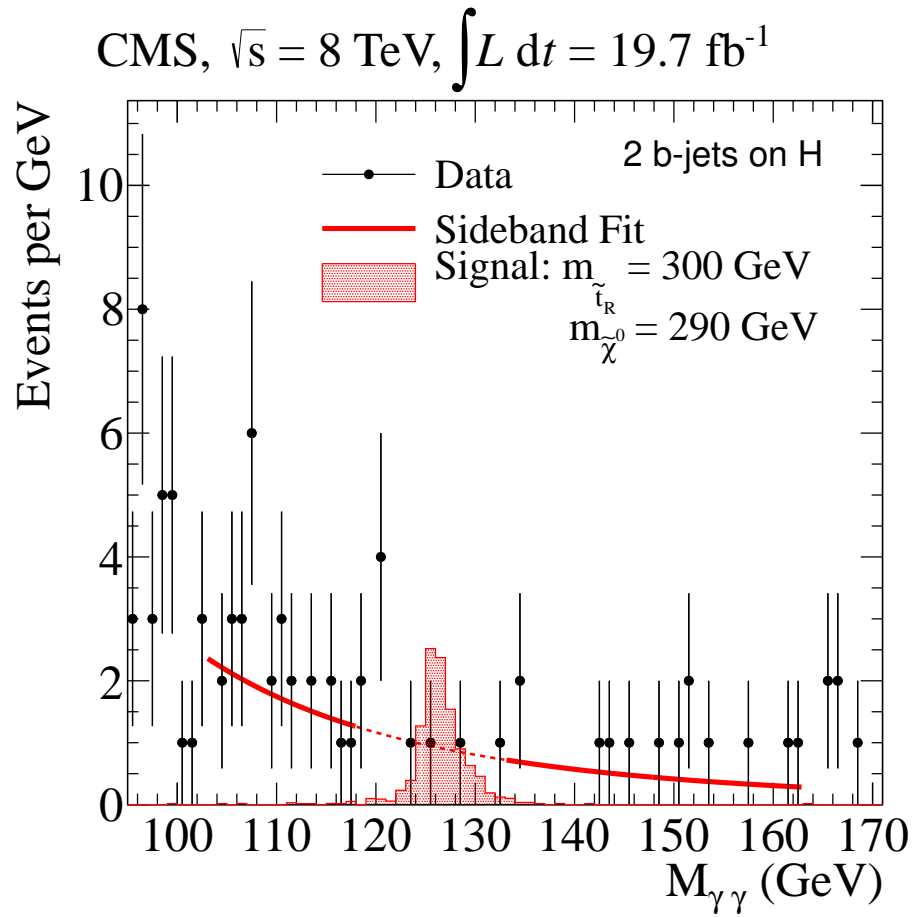


Figure 6: Diphoton mass distribution (points with errors) in event category (ii) and the power law fit (thick red line). The interval from 118 to 133 GeV is excluded from the fit.

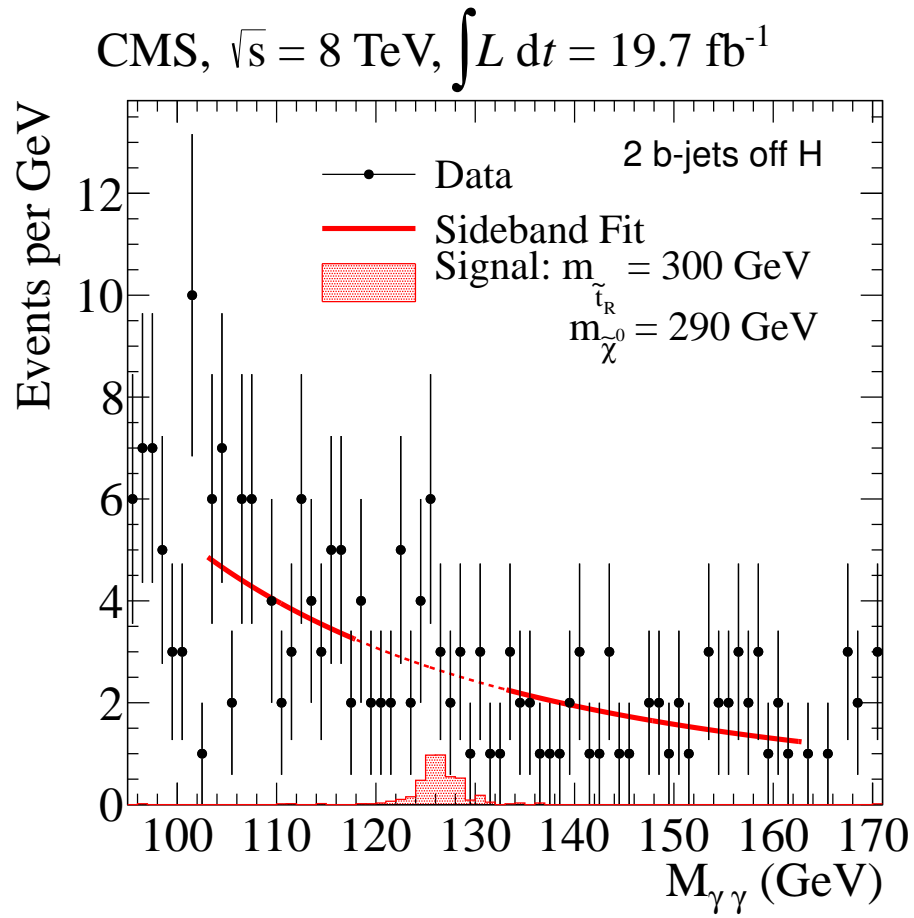


Figure 7: Diphoton mass distribution (points with errors) in event category (iii) and the power law fit (thick red line). The interval from 118 to 133 GeV is excluded from the fit.

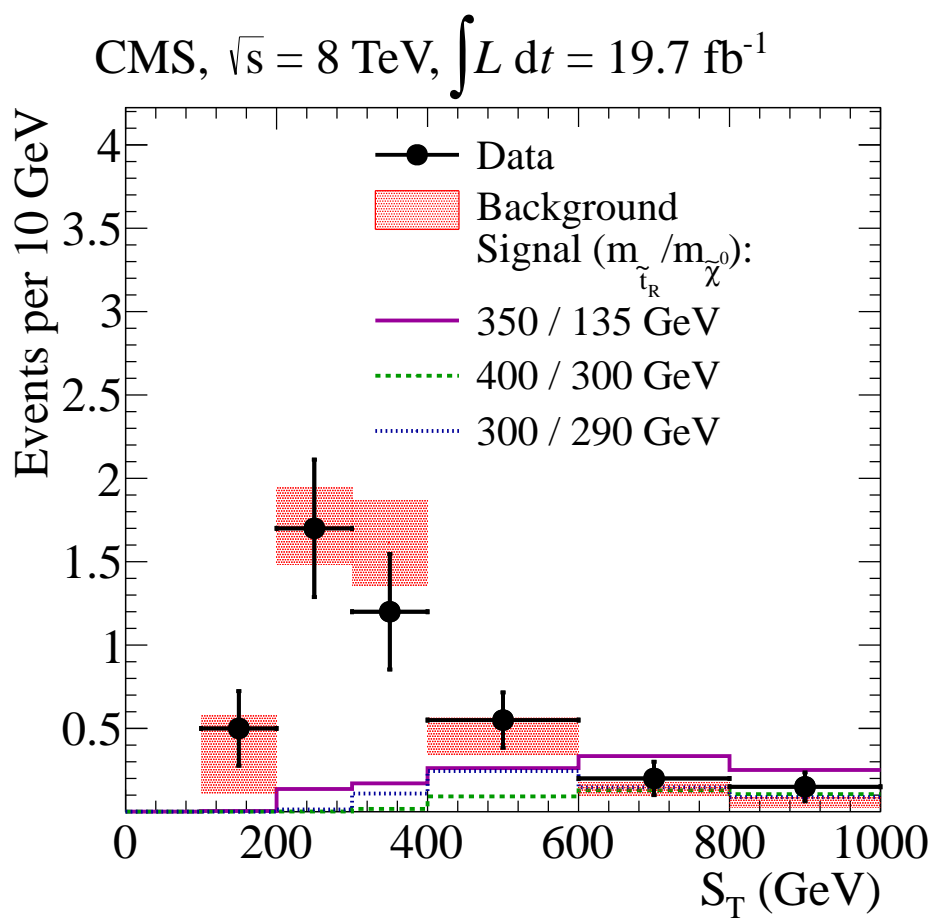


Figure 8:  $S_T$  distributions for the data, background prediction, and representative signals for the three event categories combined. The last bin includes the overflow.

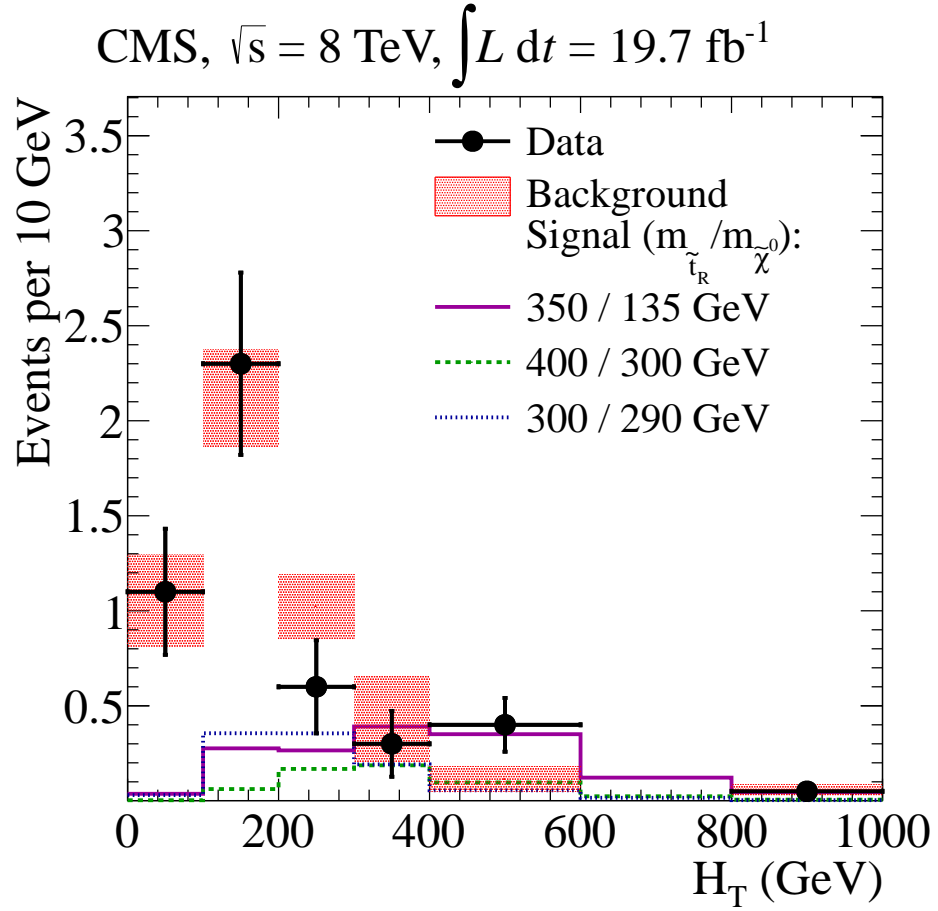


Figure 9:  $H_T$  distributions for the data, background prediction, and representative signals for the three event categories combined. The last bin includes the overflow.



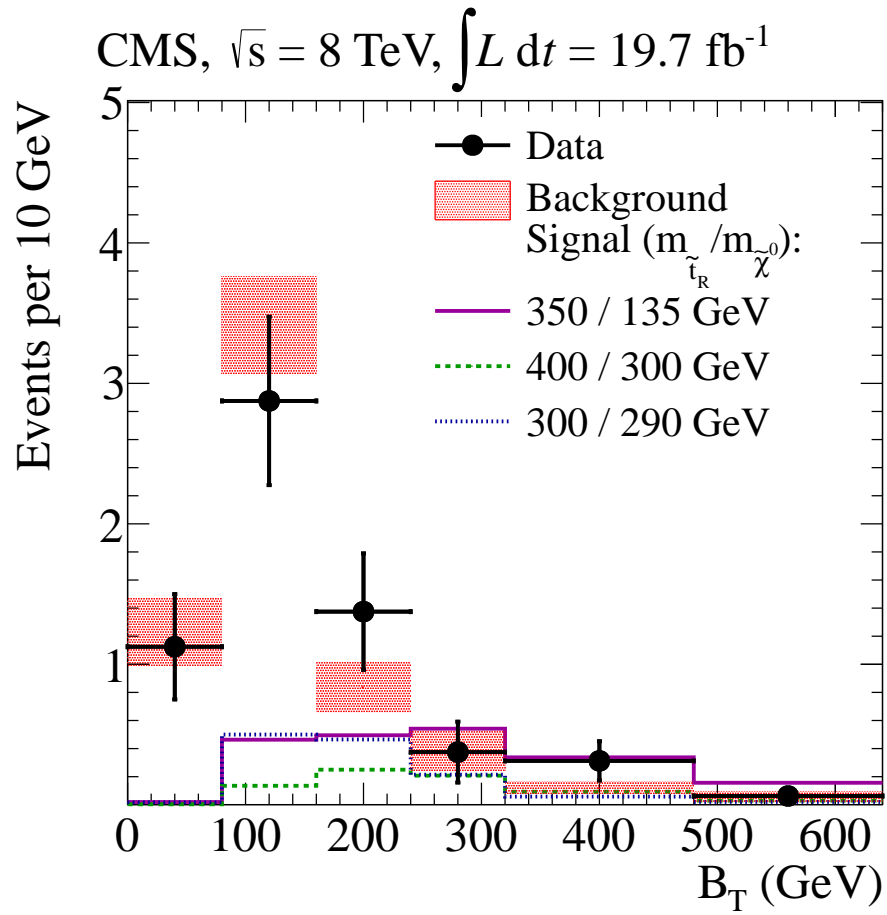


Figure 10:  $B_T$  distributions for the data, background prediction, and representative signals for the three event categories combined. The last bin includes the overflow.

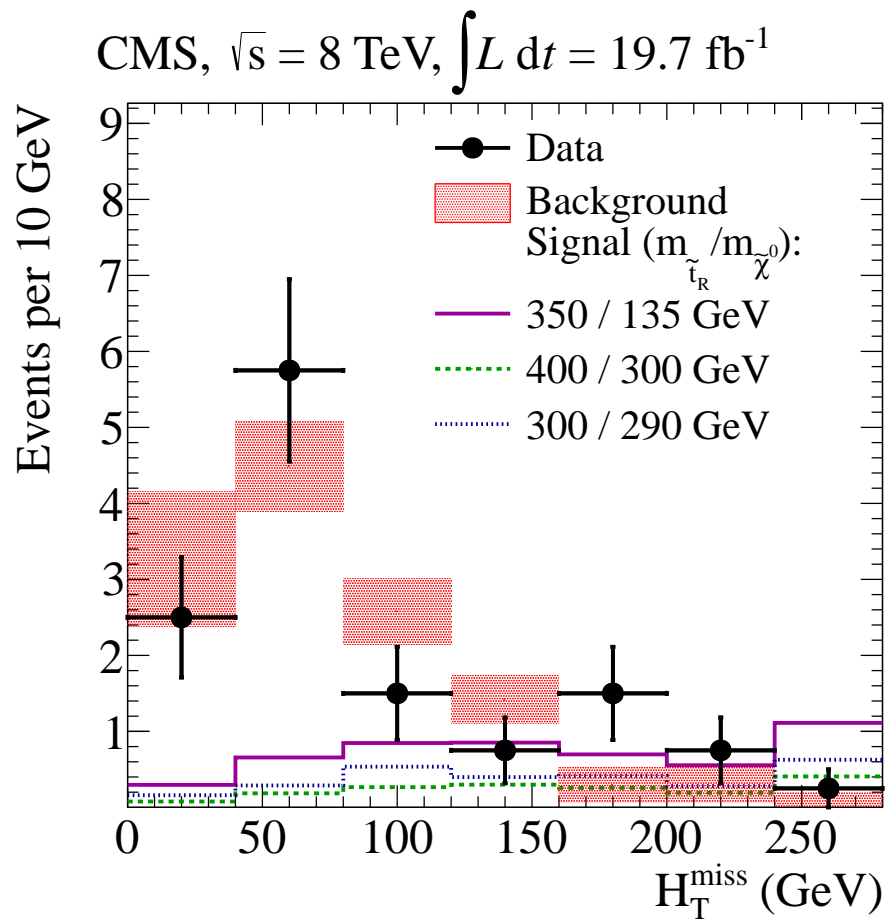


Figure 11:  $H_T^{\text{miss}}$  distributions for the data, background prediction, and representative signals for the three event categories combined. The last bin includes the overflow.

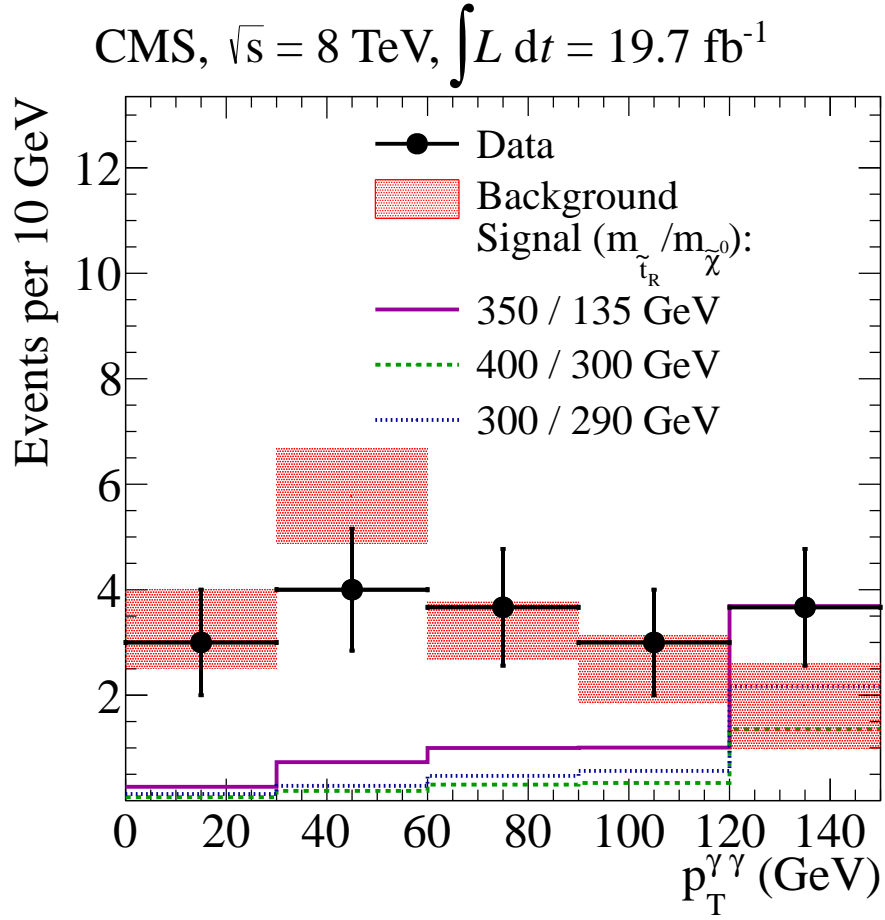


Figure 12:  $p_T^{\gamma\gamma}$  distributions for the data, background prediction, and representative signals for the three event categories combined. The last bin includes the overflow.

## C The CMS Collaboration

### Yerevan Physics Institute, Yerevan, Armenia

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

### Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan<sup>1</sup>, M. Friedl, R. Frühwirth<sup>1</sup>, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler<sup>1</sup>, W. Kiesenhofer, V. Knünz, M. Krammer<sup>1</sup>, I. Krätschmer, D. Liko, I. Mikulec, D. Rabady<sup>2</sup>, B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz<sup>1</sup>

### National Centre for Particle and High Energy Physics, Minsk, Belarus

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

### Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, H. Van Haeve, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

### Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, N. Heracleous, A. Kalogeropoulos, J. Keaveney, T.J. Kim, S. Lowette, M. Maes, A. Olbrechts, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Vilella

### Université Libre de Bruxelles, Bruxelles, Belgium

C. Caillol, B. Clerbaux, G. De Lentdecker, L. Favart, A.P.R. Gay, A. Léonard, P.E. Marage, A. Mohammadi, L. Perniè, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

### Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Dildick, G. Garcia, B. Klein, J. Lellouch, J. McCartin, A.A. Ocampo Rios, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

### Université Catholique de Louvain, Louvain-la-Neuve, Belgium

S. Basegmez, C. Beluffi<sup>3</sup>, G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silva, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco<sup>4</sup>, J. Hollar, P. Jez, M. Komm, V. Lemaître, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, A. Popov<sup>5</sup>, L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

### Université de Mons, Mons, Belgium

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

### Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

### Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

W.L. Aldá Júnior, W. Carvalho, J. Chinellato<sup>6</sup>, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote<sup>6</sup>, A. Vilela Pereira

### Universidade Estadual Paulista <sup>a</sup>, Universidade Federal do ABC <sup>b</sup>, São Paulo, Brazil

C.A. Bernardes<sup>b</sup>, F.A. Dias<sup>a,7</sup>, T.R. Fernandez Perez Tomei<sup>a</sup>, E.M. Gregores<sup>b</sup>, C. Lagana<sup>a</sup>, P.G. Mercadante<sup>b</sup>, S.F. Novaes<sup>a</sup>, Sandra S. Padula<sup>a</sup>

**Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria**

V. Genchev<sup>2</sup>, P. Iaydjiev<sup>2</sup>, A. Marinov, S. Piperov, M. Rodozov, G. Sultanov, M. Vutova

**University of Sofia, Sofia, Bulgaria**

A. Dimitrov, I. Glushkov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

**Institute of High Energy Physics, Beijing, China**

J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, R. Du, C.H. Jiang, D. Liang, S. Liang, X. Meng, R. Plestina<sup>8</sup>, J. Tao, X. Wang, Z. Wang

**State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China**

C. Asawatangkuldee, Y. Ban, Y. Guo, Q. Li, W. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, L. Zhang, W. Zou

**Universidad de Los Andes, Bogota, Colombia**

C. Avila, C.A. Carrillo Montoya, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

**Technical University of Split, Split, Croatia**

N. Godinovic, D. Lelas, D. Polic, I. Puljak

**University of Split, Split, Croatia**

Z. Antunovic, M. Kovac

**Institute Rudjer Boskovic, Zagreb, Croatia**

V. Brigljevic, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

**University of Cyprus, Nicosia, Cyprus**

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

**Charles University, Prague, Czech Republic**

M. Finger, M. Finger Jr.

**Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt**

A.A. Abdelalim<sup>9</sup>, Y. Assran<sup>10</sup>, S. Elgammal<sup>9</sup>, A. Ellithi Kamel<sup>11</sup>, M.A. Mahmoud<sup>12</sup>, A. Radi<sup>13,14</sup>

**National Institute of Chemical Physics and Biophysics, Tallinn, Estonia**

M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

**Department of Physics, University of Helsinki, Helsinki, Finland**

P. Eerola, G. Fedi, M. Voutilainen

**Helsinki Institute of Physics, Helsinki, Finland**

J. Härkönen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

**Lappeenranta University of Technology, Lappeenranta, Finland**

T. Tuuva

**DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France**

M. Besancon, F. Couderc, M. Dejdard, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, A. Nayak, J. Rander, A. Rosowsky, M. Titov

**Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France**

S. Baffioni, F. Beaudette, P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, Y. Yilmaz, A. Zabi

**Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France**

J.-L. Agram<sup>15</sup>, J. Andrea, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte<sup>15</sup>, F. Drouhin<sup>15</sup>, J.-C. Fontaine<sup>15</sup>, D. Gelé, U. Goerlach, C. Goetzmann, P. Juillot, A.-C. Le Bihan, P. Van Hove

**Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France**

S. Gadrat

**Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France**

S. Beauceron, N. Beaupere, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici, D. Contardo<sup>2</sup>, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, J.D. Ruiz Alvarez, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

**Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia**

Z. Tsamalaidze<sup>16</sup>

**RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany**

C. Autermann, S. Beranek, M. Bontenackels, B. Calpas, M. Edelhoff, L. Feld, O. Hindrichs, K. Klein, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov<sup>5</sup>

**RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany**

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, K. Padeken, P. Papacz, H. Reithler, S.A. Schmitz, L. Sonnenschein, D. Teyssier, S. Thüer, M. Weber

**RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany**

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann<sup>2</sup>, A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

**Deutsches Elektronen-Synchrotron, Hamburg, Germany**

I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, A.J. Bell, M. Bergholz<sup>17</sup>, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, A. Geiser, A. Grebenyuk, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, M. Hempel, D. Horton, H. Jung, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, M. Krämer, D. Krücker, W. Lange, J. Leonard, K. Lipka, W. Lohmann<sup>17</sup>, B. Lutz, R. Mankel, I. Marfin, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, H. Perrey, A. Petrukhin, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, R. Schmidt<sup>17</sup>, T. Schoerner-Sadenius, M. Schröder, M. Stein, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

**University of Hamburg, Hamburg, Germany**

M. Aldaya Martin, V. Blobel, H. Enderle, J. Erfle, E. Garutti, K. Goebel, M. Görner, M. Gosselink, J. Haller, R.S. Höing, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, T. Lapsien, I. Marchesini, J. Ott, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Seidel, J. Sibille<sup>18</sup>, V. Sola, H. Stadie, G. Steinbrück, D. Troendle, E. Usai, L. Vanelderen

**Institut für Experimentelle Kernphysik, Karlsruhe, Germany**

C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff<sup>2</sup>, F. Hartmann<sup>2</sup>, T. Hauth<sup>2</sup>, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov<sup>5</sup>, A. Kornmayer<sup>2</sup>, E. Kuznetsova, P. Lobelle Pardo, D. Martschei, M.U. Mozer, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, G. Quast, K. Rabbertz, F. Ratnikov, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf, M. Zeise

**Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece**

G. Anagnostou, G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, E. Ntomari, A. Psallidas, I. Topsis-giotis

**University of Athens, Athens, Greece**

L. Gouskos, A. Panagiotou, N. Saoulidou, E. Stiliaris

**University of Ioánnina, Ioánnina, Greece**

X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, J. Jones, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas

**Wigner Research Centre for Physics, Budapest, Hungary**

G. Bencze, C. Hajdu, P. Hidas, D. Horvath<sup>19</sup>, F. Sikler, V. Veszpremi, G. Vesztergombi<sup>20</sup>, A.J. Zsigmond

**Institute of Nuclear Research ATOMKI, Debrecen, Hungary**

N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

**University of Debrecen, Debrecen, Hungary**

J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

**National Institute of Science Education and Research, Bhubaneswar, India**

S.K. Swain

**Panjab University, Chandigarh, India**

S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, M. Mittal, N. Nishu, A. Sharma, J.B. Singh

**University of Delhi, Delhi, India**

Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

**Saha Institute of Nuclear Physics, Kolkata, India**

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan, A.P. Singh

**Bhabha Atomic Research Centre, Mumbai, India**

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty<sup>2</sup>, L.M. Pant, P. Shukla, A. Topkar

**Tata Institute of Fundamental Research - EHEP, Mumbai, India**

T. Aziz, R.M. Chatterjee, S. Ganguly, S. Ghosh, M. Guchait<sup>21</sup>, A. Gurtu<sup>22</sup>, G. Kole, S. Kumar, M. Maity<sup>23</sup>, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage<sup>24</sup>

**Tata Institute of Fundamental Research - HECR, Mumbai, India**

S. Banerjee, S. Dugad

**Institute for Research in Fundamental Sciences (IPM), Tehran, Iran**

H. Arfaei, H. Bakhshiansohi, H. Behnamian, S.M. Etesami<sup>25</sup>, A. Fahim<sup>26</sup>, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, B. Safarzadeh<sup>27</sup>, M. Zeinali

**University College Dublin, Dublin, Ireland**

M. Grunewald

**INFN Sezione di Bari <sup>a</sup>, Università di Bari <sup>b</sup>, Politecnico di Bari <sup>c</sup>, Bari, Italy**

M. Abbrescia<sup>a,b</sup>, L. Barbone<sup>a,b</sup>, C. Calabria<sup>a,b</sup>, S.S. Chhibra<sup>a,b</sup>, A. Colaleo<sup>a</sup>, D. Creanza<sup>a,c</sup>, N. De Filippis<sup>a,c</sup>, M. De Palma<sup>a,b</sup>, L. Fiore<sup>a</sup>, G. Iaselli<sup>a,c</sup>, G. Maggi<sup>a,c</sup>, M. Maggi<sup>a</sup>, B. Marangelli<sup>a,b</sup>, S. My<sup>a,c</sup>, S. Nuzzo<sup>a,b</sup>, N. Pacifico<sup>a</sup>, A. Pompili<sup>a,b</sup>, G. Pugliese<sup>a,c</sup>, R. Radogna<sup>a,b</sup>, G. Selvaggi<sup>a,b</sup>, L. Silvestris<sup>a</sup>, G. Singh<sup>a,b</sup>, R. Venditti<sup>a,b</sup>, P. Verwilligen<sup>a</sup>, G. Zito<sup>a</sup>

**INFN Sezione di Bologna <sup>a</sup>, Università di Bologna <sup>b</sup>, Bologna, Italy**

G. Abbiendi<sup>a</sup>, A.C. Benvenuti<sup>a</sup>, D. Bonacorsi<sup>a,b</sup>, S. Braibant-Giacomelli<sup>a,b</sup>, L. Brigliadori<sup>a,b</sup>, R. Campanini<sup>a,b</sup>, P. Capiluppi<sup>a,b</sup>, A. Castro<sup>a,b</sup>, F.R. Cavallo<sup>a</sup>, G. Codispoti<sup>a,b</sup>, M. Cuffiani<sup>a,b</sup>, G.M. Dallavalle<sup>a</sup>, F. Fabbri<sup>a</sup>, A. Fanfani<sup>a,b</sup>, D. Fasanella<sup>a,b</sup>, P. Giacomelli<sup>a</sup>, C. Grandi<sup>a</sup>, L. Guiducci<sup>a,b</sup>, S. Marcellini<sup>a</sup>, G. Masetti<sup>a</sup>, M. Meneghelli<sup>a,b</sup>, A. Montanari<sup>a</sup>, F.L. Navarria<sup>a,b</sup>, F. Odorici<sup>a</sup>, A. Perrotta<sup>a</sup>, F. Primavera<sup>a,b</sup>, A.M. Rossi<sup>a,b</sup>, T. Rovelli<sup>a,b</sup>, G.P. Siroli<sup>a,b</sup>, N. Tosi<sup>a,b</sup>, R. Travaglini<sup>a,b</sup>

**INFN Sezione di Catania <sup>a</sup>, Università di Catania <sup>b</sup>, CSFNSM <sup>c</sup>, Catania, Italy**

S. Albergo<sup>a,b</sup>, G. Cappello<sup>a</sup>, M. Chiorboli<sup>a,b</sup>, S. Costa<sup>a,b</sup>, F. Giordano<sup>a,c,2</sup>, R. Potenza<sup>a,b</sup>, A. Tricomi<sup>a,b</sup>, C. Tuve<sup>a,b</sup>

**INFN Sezione di Firenze <sup>a</sup>, Università di Firenze <sup>b</sup>, Firenze, Italy**

G. Barbagli<sup>a</sup>, V. Ciulli<sup>a,b</sup>, C. Civinini<sup>a</sup>, R. D'Alessandro<sup>a,b</sup>, E. Focardi<sup>a,b</sup>, E. Gallo<sup>a</sup>, S. Gonzi<sup>a,b</sup>, V. Gori<sup>a,b</sup>, P. Lenzi<sup>a,b</sup>, M. Meschini<sup>a</sup>, S. Paoletti<sup>a</sup>, G. Sguazzoni<sup>a</sup>, A. Tropiano<sup>a,b</sup>

**INFN Laboratori Nazionali di Frascati, Frascati, Italy**

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

**INFN Sezione di Genova <sup>a</sup>, Università di Genova <sup>b</sup>, Genova, Italy**

P. Fabbricatore<sup>a</sup>, R. Ferretti<sup>a,b</sup>, F. Ferro<sup>a</sup>, M. Lo Vetere<sup>a,b</sup>, R. Musenich<sup>a</sup>, E. Robutti<sup>a</sup>, S. Tosi<sup>a,b</sup>

**INFN Sezione di Milano-Bicocca <sup>a</sup>, Università di Milano-Bicocca <sup>b</sup>, Milano, Italy**

A. Benaglia<sup>a</sup>, M.E. Dinardo<sup>a,b</sup>, S. Fiorendi<sup>a,b,2</sup>, S. Gennai<sup>a</sup>, R. Gerosa, A. Ghezzi<sup>a,b</sup>, P. Govoni<sup>a,b</sup>, M.T. Lucchini<sup>a,b,2</sup>, S. Malvezzi<sup>a</sup>, R.A. Manzoni<sup>a,b,2</sup>, A. Martelli<sup>a,b,2</sup>, B. Marzocchi, D. Menasce<sup>a</sup>, L. Moroni<sup>a</sup>, M. Paganoni<sup>a,b</sup>, D. Pedrini<sup>a</sup>, S. Ragazzi<sup>a,b</sup>, N. Redaelli<sup>a</sup>, T. Tabarelli de Fatis<sup>a,b</sup>

**INFN Sezione di Napoli <sup>a</sup>, Università di Napoli 'Federico II' <sup>b</sup>, Università della Basilicata (Potenza) <sup>c</sup>, Università G. Marconi (Roma) <sup>d</sup>, Napoli, Italy**

S. Buontempo<sup>a</sup>, N. Cavallo<sup>a,c</sup>, F. Fabozzi<sup>a,c</sup>, A.O.M. Iorio<sup>a,b</sup>, L. Lista<sup>a</sup>, S. Meola<sup>a,d,2</sup>, M. Merola<sup>a</sup>, P. Paolucci<sup>a,2</sup>



**INFN Sezione di Padova <sup>a</sup>, Università di Padova <sup>b</sup>, Università di Trento (Trento) <sup>c</sup>, Padova, Italy**

P. Azzi<sup>a</sup>, N. Bacchetta<sup>a</sup>, D. Bisello<sup>a,b</sup>, A. Branca<sup>a,b</sup>, R. Carlin<sup>a,b</sup>, P. Checchia<sup>a</sup>, T. Dorigo<sup>a</sup>, M. Galanti<sup>a,b,2</sup>, F. Gasparini<sup>a,b</sup>, U. Gasparini<sup>a,b</sup>, P. Giubilato<sup>a,b</sup>, A. Gozzelino<sup>a</sup>, K. Kanishchev<sup>a,c</sup>, S. Lacaprara<sup>a</sup>, I. Lazzizzera<sup>a,c</sup>, M. Margoni<sup>a,b</sup>, A.T. Meneguzzo<sup>a,b</sup>, M. Passaseo<sup>a</sup>, J. Pazzini<sup>a,b</sup>, M. Pegoraro<sup>a</sup>, N. Pozzobon<sup>a,b</sup>, P. Ronchese<sup>a,b</sup>, F. Simonetto<sup>a,b</sup>, E. Torassa<sup>a</sup>, M. Tosi<sup>a,b</sup>, A. Triossi<sup>a</sup>, S. Ventura<sup>a</sup>, A. Zucchetta<sup>a,b</sup>, G. Zumerle<sup>a,b</sup>

**INFN Sezione di Pavia <sup>a</sup>, Università di Pavia <sup>b</sup>, Pavia, Italy**

M. Gabusi<sup>a,b</sup>, S.P. Ratti<sup>a,b</sup>, C. Riccardi<sup>a,b</sup>, P. Vitulo<sup>a,b</sup>

**INFN Sezione di Perugia <sup>a</sup>, Università di Perugia <sup>b</sup>, Perugia, Italy**

M. Biasini<sup>a,b</sup>, G.M. Bilei<sup>a</sup>, L. Fanò<sup>a,b</sup>, P. Lariccia<sup>a,b</sup>, G. Mantovani<sup>a,b</sup>, M. Menichelli<sup>a</sup>, F. Romeo<sup>a,b</sup>, A. Saha<sup>a</sup>, A. Santocchia<sup>a,b</sup>, A. Spiezia<sup>a,b</sup>

**INFN Sezione di Pisa <sup>a</sup>, Università di Pisa <sup>b</sup>, Scuola Normale Superiore di Pisa <sup>c</sup>, Pisa, Italy**

K. Androsov<sup>a,28</sup>, P. Azzurri<sup>a</sup>, G. Bagliesi<sup>a</sup>, J. Bernardini<sup>a</sup>, T. Boccali<sup>a</sup>, G. Broccolo<sup>a,c</sup>, R. Castaldi<sup>a</sup>, M.A. Ciocci<sup>a,28</sup>, R. Dell'Orso<sup>a</sup>, F. Fiori<sup>a,c</sup>, L. Foà<sup>a,c</sup>, A. Giassi<sup>a</sup>, M.T. Grippo<sup>a,28</sup>, A. Kraan<sup>a</sup>, F. Ligabue<sup>a,c</sup>, T. Lomtadze<sup>a</sup>, L. Martini<sup>a,b</sup>, A. Messineo<sup>a,b</sup>, C.S. Moon<sup>a,29</sup>, F. Palla<sup>a</sup>, A. Rizzi<sup>a,b</sup>, A. Savoy-Navarro<sup>a,30</sup>, A.T. Serban<sup>a</sup>, P. Spagnolo<sup>a</sup>, P. Squillacioti<sup>a,28</sup>, R. Tenchini<sup>a</sup>, G. Tonelli<sup>a,b</sup>, A. Venturi<sup>a</sup>, P.G. Verдини<sup>a</sup>, C. Vernieri<sup>a,c</sup>

**INFN Sezione di Roma <sup>a</sup>, Università di Roma <sup>b</sup>, Roma, Italy**

L. Barone<sup>a,b</sup>, F. Cavallari<sup>a</sup>, D. Del Re<sup>a,b</sup>, M. Diemoz<sup>a</sup>, M. Grassi<sup>a,b</sup>, C. Jorda<sup>a</sup>, E. Longo<sup>a,b</sup>, F. Margaroli<sup>a,b</sup>, P. Meridiani<sup>a</sup>, F. Micheli<sup>a,b</sup>, S. Nourbakhsh<sup>a,b</sup>, G. Organtini<sup>a,b</sup>, R. Paramatti<sup>a</sup>, S. Rahatlou<sup>a,b</sup>, C. Rovelli<sup>a</sup>, L. Soffi<sup>a,b</sup>, P. Traczyk<sup>a,b</sup>

**INFN Sezione di Torino <sup>a</sup>, Università di Torino <sup>b</sup>, Università del Piemonte Orientale (Novara) <sup>c</sup>, Torino, Italy**

N. Amapane<sup>a,b</sup>, R. Arcidiacono<sup>a,c</sup>, S. Argiro<sup>a,b</sup>, M. Arneodo<sup>a,c</sup>, R. Bellan<sup>a,b</sup>, C. Biino<sup>a</sup>, N. Cartiglia<sup>a</sup>, S. Casasso<sup>a,b</sup>, M. Costa<sup>a,b</sup>, A. Degano<sup>a,b</sup>, N. Demaria<sup>a</sup>, C. Mariotti<sup>a</sup>, S. Maselli<sup>a</sup>, E. Migliore<sup>a,b</sup>, V. Monaco<sup>a,b</sup>, M. Musich<sup>a</sup>, M.M. Obertino<sup>a,c</sup>, G. Ortona<sup>a,b</sup>, L. Pacher<sup>a,b</sup>, N. Pastrone<sup>a</sup>, M. Pelliccioni<sup>a,2</sup>, A. Potenza<sup>a,b</sup>, A. Romero<sup>a,b</sup>, M. Ruspa<sup>a,c</sup>, R. Sacchi<sup>a,b</sup>, A. Solano<sup>a,b</sup>, A. Staiano<sup>a</sup>, U. Tamponi<sup>a</sup>

**INFN Sezione di Trieste <sup>a</sup>, Università di Trieste <sup>b</sup>, Trieste, Italy**

S. Belforte<sup>a</sup>, V. Candelise<sup>a,b</sup>, M. Casarsa<sup>a</sup>, F. Cossutti<sup>a</sup>, G. Della Ricca<sup>a,b</sup>, B. Gobbo<sup>a</sup>, C. La Licata<sup>a,b</sup>, M. Marone<sup>a,b</sup>, D. Montanino<sup>a,b</sup>, A. Penzo<sup>a</sup>, A. Schizzi<sup>a,b</sup>, T. Umer<sup>a,b</sup>, A. Zanetti<sup>a</sup>

**Kangwon National University, Chunchon, Korea**

S. Chang, T.Y. Kim, S.K. Nam

**Kyungpook National University, Daegu, Korea**

D.H. Kim, G.N. Kim, J.E. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, H. Park, D.C. Son

**Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea**

J.Y. Kim, Zero J. Kim, S. Song

**Korea University, Seoul, Korea**

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, K.S. Lee, S.K. Park, Y. Roh

**University of Seoul, Seoul, Korea**

M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

**Sungkyunkwan University, Suwon, Korea**

Y. Choi, Y.K. Choi, J. Goh, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

**Vilnius University, Vilnius, Lithuania**

A. Juodagalvis

**University of Malaya Jabatan Fizik, Kuala Lumpur, Malaysia**

J.R. Komaragiri

**Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico**

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz<sup>31</sup>, R. Lopez-Fernandez, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

**Universidad Iberoamericana, Mexico City, Mexico**

S. Carrillo Moreno, F. Vazquez Valencia

**Benemerita Universidad Autonoma de Puebla, Puebla, Mexico**

H.A. Salazar Ibarguen

**Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico**

E. Casimiro Linares, A. Morelos Pineda

**University of Auckland, Auckland, New Zealand**

D. Krofcheck

**University of Canterbury, Christchurch, New Zealand**

P.H. Butler, R. Doesburg, S. Reucroft

**National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan**

M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

**National Centre for Nuclear Research, Swierk, Poland**

H. Bialkowska, M. Bluj<sup>32</sup>, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

**Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland**

G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, W. Wolszczak

**Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal**

P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, F. Nguyen, J. Rodrigues Antunes, J. Seixas<sup>2</sup>, J. Varela, P. Vischia

**Joint Institute for Nuclear Research, Dubna, Russia**

M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev<sup>33</sup>, P. Moisenz, V. Palichik, V. Pereygin, M. Savina, S. Shmatov, N. Skatchkov, V. Smirnov, A. Zarubin

**Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia**

V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

**Institute for Nuclear Research, Moscow, Russia**

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

**Institute for Theoretical and Experimental Physics, Moscow, Russia**

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

**P.N. Lebedev Physical Institute, Moscow, Russia**

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

**Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia**

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin<sup>7</sup>, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin

**State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia**

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

**University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia**

P. Adzic<sup>34</sup>, M. Djordjevic, M. Ekmedzic, J. Milosevic

**Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain**

M. Aguilar-Benitez, J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas<sup>2</sup>, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, E. Navarro De Martino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares, C. Willmott

**Universidad Autónoma de Madrid, Madrid, Spain**

C. Albajar, J.F. de Trocóniz, M. Missiroli

**Universidad de Oviedo, Oviedo, Spain**

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias

**Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain**

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

**CERN, European Organization for Nuclear Research, Geneva, Switzerland**

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, L. Benhabib, J.F. Benitez, C. Bernet<sup>8</sup>, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, S. Colafranceschi<sup>35</sup>, M. D'Alfonso, D. d'Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, G. Franzoni, W. Funk, M. Giffels, D. Gigi, K. Gill, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, V. Innocente, P. Janot, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, M. Mulders, P. Musella, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, G. Petrucciani, A. Pfeiffer,

M. Pierini, M. Pimiä, D. Piparo, M. Plagge, A. Racz, W. Reece, G. Rolandi<sup>36</sup>, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas<sup>37</sup>, J. Steggemann, B. Stieger, M. Stoye, A. Tsirou, G.I. Veres<sup>20</sup>, J.R. Vlimant, H.K. Wöhri, W.D. Zeuner

**Paul Scherrer Institut, Villigen, Switzerland**

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

**Institute for Particle Physics, ETH Zurich, Zurich, Switzerland**

F. Bachmair, L. Bäni, L. Bianchini, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, W. Lustermann, B. Mangano, A.C. Marini, P. Martinez Ruiz del Arbol, D. Meister, N. Mohr, C. Nägeli<sup>38</sup>, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, M. Quittnat, F.J. Ronga, M. Rossini, A. Starodumov<sup>39</sup>, M. Takahashi, L. Tauscher<sup>†</sup>, K. Theofilatos, D. Treille, R. Wallny, H.A. Weber

**Universität Zürich, Zurich, Switzerland**

C. AMSLER<sup>40</sup>, V. Chiochia, A. De Cosa, C. Favaro, A. Hinzmann, T. Hreus, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, J. Ngadiuba, P. Robmann, H. Snoek, S. Taroni, M. Verzetti, Y. Yang

**National Central University, Chung-Li, Taiwan**

M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

**National Taiwan University (NTU), Taipei, Taiwan**

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, Y.F. Liu, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang, R. Wilken

**Chulalongkorn University, Bangkok, Thailand**

B. Asavapibhop, N. Suwonjandee

**Cukurova University, Adana, Turkey**

A. Adiguzel, M.N. Bakirci<sup>41</sup>, S. Cerci<sup>42</sup>, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut<sup>43</sup>, K. Ozdemir, S. Ozturk<sup>41</sup>, A. Polatoz, K. Sogut<sup>44</sup>, D. Sunar Cerci<sup>42</sup>, B. Tali<sup>42</sup>, H. Topakli<sup>41</sup>, M. Vergili

**Middle East Technical University, Physics Department, Ankara, Turkey**

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, G. Karapinar<sup>45</sup>, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

**Bogazici University, Istanbul, Turkey**

E. Gülmez, B. Isildak<sup>46</sup>, M. Kaya<sup>47</sup>, O. Kaya<sup>47</sup>, S. Ozkorucuklu<sup>48</sup>

**Istanbul Technical University, Istanbul, Turkey**

H. Bahtiyar<sup>49</sup>, E. Barlas, K. Cankocak, Y.O. Günaydin<sup>50</sup>, F.I. Vardarli, M. Yücel

**National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine**

L. Levchuk, P. Sorokin

**University of Bristol, Bristol, United Kingdom**

J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold<sup>51</sup>, S. Paramesvaran, A. Poll, S. Senkin, V.J. Smith, T. Williams

**Rutherford Appleton Laboratory, Didcot, United Kingdom**

K.W. Bell, A. Belyaev<sup>52</sup>, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Ilic, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, W.J. Womersley, S.D. Worm

**Imperial College, London, United Kingdom**

M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas<sup>51</sup>, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko<sup>39</sup>, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi<sup>53</sup>, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp<sup>†</sup>, A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle

**Brunel University, Uxbridge, United Kingdom**

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

**Baylor University, Waco, USA**

J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

**The University of Alabama, Tuscaloosa, USA**

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

**Boston University, Boston, USA**

A. Avetisyan, T. Bose, C. Fantasia, A. Heister, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, J. St. John, L. Sulak

**Brown University, Providence, USA**

J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer, J. Swanson

**University of California, Davis, Davis, USA**

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, A. Kopecky, R. Lander, T. Miceli, D. Pellett, J. Pilot, F. Ricci-Tam, B. Rutherford, M. Searle, S. Shalhout, J. Smith, M. Squires, M. Tripathi, S. Wilbur, R. Yohay

**University of California, Los Angeles, USA**

V. Andreev, D. Cline, R. Cousins, S. Erhan, P. Everaerts, C. Farrell, M. Felcini, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein<sup>†</sup>, E. Takasugi, V. Valuev, M. Weber

**University of California, Riverside, Riverside, USA**

J. Babb, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, P. Jandir, F. Lacroix, H. Liu, O.R. Long, A. Luthra, M. Malberti, H. Nguyen, A. Shrinivas, J. Sturdy, S. Sumowidagdo, S. Wimpenny

**University of California, San Diego, La Jolla, USA**

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, D. Evans, A. Holzner, R. Kelley, D. Kovalskyi, M. Lebourgeois, J. Letts, I. Macneill, S. Padhi, C. Palmer, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech<sup>54</sup>, F. Würthwein, A. Yagil, J. Yoo

**University of California, Santa Barbara, Santa Barbara, USA**

D. Barge, C. Campagnari, T. Danielson, K. Flowers, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Richman, R. Rossin, D. Stuart, W. To, C. West

**California Institute of Technology, Pasadena, USA**

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, D. Kcira, A. Mott, H.B. Newman, C. Pena, C. Rogan, M. Spiropulu, V. Timciuc, R. Wilkinson, S. Xie, R.Y. Zhu

**Carnegie Mellon University, Pittsburgh, USA**

V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

**University of Colorado at Boulder, Boulder, USA**

J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

**Cornell University, Ithaca, USA**

J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, W. Hopkins, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

**Fairfield University, Fairfield, USA**

D. Winn

**Fermi National Accelerator Laboratory, Batavia, USA**

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, K. Kaadze, B. Klima, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko<sup>33</sup>, S. Nahn, C. Newman-Holmes, V. O'Dell, O. Prokofyev, N. Ratnikova, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, W. Wu, F. Yang, J.C. Yun

**University of Florida, Gainesville, USA**

D. Acosta, P. Avery, D. Bourilkov, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic<sup>55</sup>, G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

**Florida International University, Miami, USA**

V. Gaultney, S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

**Florida State University, Tallahassee, USA**

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

**Florida Institute of Technology, Melbourne, USA**

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, F. Yumiceva

**University of Illinois at Chicago (UIC), Chicago, USA**

M.R. Adams, L. Apanasevich, V.E. Bazterra, R.R. Betts, I. Bucinskaite, R. Cavanaugh,

O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, D.H. Moon, C. O'Brien, C. Silkworth, P. Turner, N. Varelas

**The University of Iowa, Iowa City, USA**

U. Akgun, E.A. Albayrak<sup>49</sup>, B. Bilki<sup>56</sup>, W. Clarida, K. Dilsiz, F. Duru, M. Haytmyradov, J.-P. Merlo, H. Mermerkaya<sup>57</sup>, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok<sup>49</sup>, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin<sup>58</sup>, K. Yi

**Johns Hopkins University, Baltimore, USA**

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz

**The University of Kansas, Lawrence, USA**

P. Baringer, A. Bean, G. Benelli, R.P. Kenny III, M. Murray, D. Noonan, S. Sanders, J. Sekaric, R. Stringer, Q. Wang, J.S. Wood

**Kansas State University, Manhattan, USA**

A.F. Barfuss, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, L.K. Saini, S. Shrestha, I. Svintradze

**Lawrence Livermore National Laboratory, Livermore, USA**

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

**University of Maryland, College Park, USA**

A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

**Massachusetts Institute of Technology, Cambridge, USA**

A. Apyan, R. Barbieri, G. Bauer, W. Busza, I.A. Cali, M. Chan, L. Di Matteo, V. Dutta, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, T. Ma, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, A.S. Yoon, M. Zanetti, V. Zhukova

**University of Minnesota, Minneapolis, USA**

B. Dahmes, A. De Benedetti, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

**University of Mississippi, Oxford, USA**

J.G. Acosta, L.M. Cremaldi, R. Kroeger, S. Oliveros, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

**University of Nebraska-Lincoln, Lincoln, USA**

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, R. Gonzalez Suarez, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, G.R. Snow

**State University of New York at Buffalo, Buffalo, USA**

J. Dolen, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio

**Northeastern University, Boston, USA**

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, A. Massironi, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

**Northwestern University, Evanston, USA**

A. Anastasov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

**University of Notre Dame, Notre Dame, USA**

D. Berry, A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf, A. Woodard

**The Ohio State University, Columbus, USA**

L. Antonelli, B. Bylsma, L.S. Durkin, S. Flowers, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, C. Vuosalo, B.L. Winer, H. Wolfe, H.W. Wulsin

**Princeton University, Princeton, USA**

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

**University of Puerto Rico, Mayaguez, USA**

E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

**Purdue University, West Lafayette, USA**

E. Alagoz, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jha, M. Jones, K. Jung, M. Kress, N. Leonardo, D. Lopes Pegna, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, I. Shipsey, D. Silvers, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

**Purdue University Calumet, Hammond, USA**

N. Parashar

**Rice University, Houston, USA**

A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

**University of Rochester, Rochester, USA**

B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, G. Petrillo, D. Vishnevskiy, M. Zielinski

**The Rockefeller University, New York, USA**

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulios, G. Lungu, S. Malik, C. Mesropian

**Rutgers, The State University of New Jersey, Piscataway, USA**

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

**University of Tennessee, Knoxville, USA**

K. Rose, S. Spanier, Z.C. Yang, A. York

**Texas A&M University, College Station, USA**

O. Bouhali<sup>59</sup>, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon<sup>60</sup>, V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, I. Suarez, A. Tatarinov, D. Toback

**Texas Tech University, Lubbock, USA**

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Dudero, K. Kovitanggoon, S. Kunori, S.W. Lee, T. Libeiro, I. Volobouev



**Vanderbilt University, Nashville, USA**

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

**University of Virginia, Charlottesville, USA**

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

**Wayne State University, Detroit, USA**

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane

**University of Wisconsin, Madison, USA**

D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, S. Duric, E. Friis, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, A. Levine, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, A. Sakharov, T. Sarangi, A. Savin, W.H. Smith

†: Deceased

- 1: Also at Vienna University of Technology, Vienna, Austria
- 2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 3: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
- 4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
- 5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
- 6: Also at Universidade Estadual de Campinas, Campinas, Brazil
- 7: Also at California Institute of Technology, Pasadena, USA
- 8: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 9: Also at Zewail City of Science and Technology, Zewail, Egypt
- 10: Also at Suez Canal University, Suez, Egypt
- 11: Also at Cairo University, Cairo, Egypt
- 12: Also at Fayoum University, El-Fayoum, Egypt
- 13: Also at British University in Egypt, Cairo, Egypt
- 14: Now at Ain Shams University, Cairo, Egypt
- 15: Also at Université de Haute Alsace, Mulhouse, France
- 16: Also at Joint Institute for Nuclear Research, Dubna, Russia
- 17: Also at Brandenburg University of Technology, Cottbus, Germany
- 18: Also at The University of Kansas, Lawrence, USA
- 19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 20: Also at Eötvös Loránd University, Budapest, Hungary
- 21: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
- 22: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 23: Also at University of Visva-Bharati, Santiniketan, India
- 24: Also at University of Ruhuna, Matara, Sri Lanka
- 25: Also at Isfahan University of Technology, Isfahan, Iran
- 26: Also at Sharif University of Technology, Tehran, Iran
- 27: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 28: Also at Università degli Studi di Siena, Siena, Italy
- 29: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
- 30: Also at Purdue University, West Lafayette, USA

- 
- 31: Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico
  - 32: Also at National Centre for Nuclear Research, Swierk, Poland
  - 33: Also at Institute for Nuclear Research, Moscow, Russia
  - 34: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
  - 35: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
  - 36: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
  - 37: Also at University of Athens, Athens, Greece
  - 38: Also at Paul Scherrer Institut, Villigen, Switzerland
  - 39: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
  - 40: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
  - 41: Also at Gaziosmanpasa University, Tokat, Turkey
  - 42: Also at Adiyaman University, Adiyaman, Turkey
  - 43: Also at Cag University, Mersin, Turkey
  - 44: Also at Mersin University, Mersin, Turkey
  - 45: Also at Izmir Institute of Technology, Izmir, Turkey
  - 46: Also at Ozyegin University, Istanbul, Turkey
  - 47: Also at Kafkas University, Kars, Turkey
  - 48: Also at Istanbul University, Faculty of Science, Istanbul, Turkey
  - 49: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
  - 50: Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey
  - 51: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
  - 52: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
  - 53: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
  - 54: Also at Utah Valley University, Orem, USA
  - 55: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
  - 56: Also at Argonne National Laboratory, Argonne, USA
  - 57: Also at Erzincan University, Erzincan, Turkey
  - 58: Also at Yildiz Technical University, Istanbul, Turkey
  - 59: Also at Texas A&M University at Qatar, Doha, Qatar
  - 60: Also at Kyungpook National University, Daegu, Korea